Isolating the Control Loop

by Robert Mammano

TOPIC 2

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Bob Mammano

Isolation Requirements

A fact of life for all off-line power supply systems is the requirement for galvanic isolation from input to output. This isolation is primarily in the interest of safety to insure that there will be no shock hazard in using the equipment, and the requirements have been quantized over the years by many agencies throughout the world, most notably VDE and IEC in Europe, and UL in the United States. Examples of some of the more stringent of these specifications are listed in Table 1. Note that isolation involves mechanical as well as electrical specifications, and as new technologies shrink component sizes, these physical spacings can often become limiting factors. For those unfamiliar with the terminology, the following definitions are offered:

Creepage is defined as the shortest path between two conductive parts on opposite sides of the isolation as measured along the surface of any intervening insulation. The best example of Creepage is the separation between two PC board solder eyes as measured along the surface of the board. Clearance denotes the shortest distance between two conductive parts as measured through the air, for example, the closest spacing of two bare leads as they run from the PC board to the point where they become insulated. Finally, the Isolation Barrier represents the shortest distance between two conductive parts separated by a dielectric which meets the voltage and resistance specifications. With an optocoupler, this is the minimum spacing of conductors within a plastic molded package. Transformer windings have the additional requirement for three separate layers of insulation, any two of which are capable of withstanding the required voltage.

All AC mains connected power supplies must provide this isolation between the input and output sections of the supply and, of course, this is normally accomplished with a power transformer. At 60 Hertz, this represents a big, heavy, and costly solution, albeit a simple one. With switch-mode power systems, the high frequencies make the power transformer much

Table I -- Examples of Safety Standards and Specifications

Standard		Equipment	Requirements for insulation for equipment with an operating voltage up to 250 VRMS				
VDE	DIN IEC		Creepage [mm]	Clearance [mm]	Isolation Barrier [mm]	Dielectric Strength [kVrms]	Isolation Resistance [Ω]
0806	380	Office Machines	8	8	0.5	3.75	7×10^6
0805	435	Data Processing	8	8	—	3.75	7×10^6
0804	—	Telecommunication	8	8	—	2.50	2×10^6
0860	65	Electr. Household	6	6	0.4	3.0	4×10^6
0113	204	Industrial Controls	8	8	—	2.50	1×10^6
0160	—	Power Installations	8	8	—	2.70	1×10^6
0832	—	Traffic Light Controls	8	8	—	2.50	4×10^6
0883	—	Alarm Systems	8	8	—	2.50	2×10^6
0831	—	El. Signal Syst. for Railroads	8	8	—	2.0	2×10^6
0110	—	General Std. for Electrical Equip.	8	8	—	2.0	—

more manageable but a new problem is introduced: the fact that the power has to be switched on the input side, but under control from the output side in order to provide good regulation. This implies a second crossing of the isolation boundary in order to feed back control information, and although this path involves only information, rather than power, it must still meet the same isolation requirements. While the isolation within the power transformer is not a trivial matter, it is the purpose of this discussion to address only the problems associated with isolating the control path.

Alternatives for Isolating Control

Figure 1 shows the block diagram of a basic off-line power converter indicating some of the places where a designer might choose to insert isolation in the control feedback path. Working from output back to input, these options are:

1. Isolating the measurement of the output voltage. While this can be accomplished fairly easily, high accuracy is required in coupling this large control signal across the isolation boundary to achieve good output regulation.

2. Isolating the analog error signal. Certainly the most popular approach and several techniques will be discussed in detail. The requirements for absolute accuracy are substantially reduced as it is only the error difference between the output and the reference which crosses the isolation.

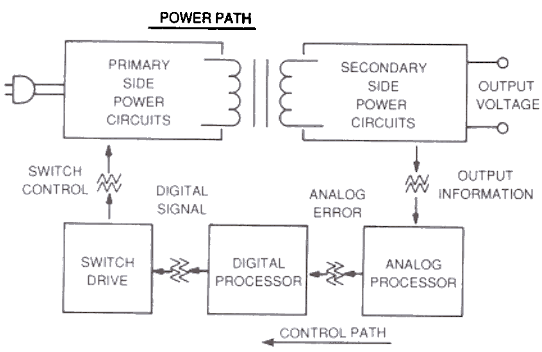

Fig. 1 -- Alternative Isolation Points

3. Isolating the digital signal path. This means after the analog-to-digital conversion which takes place in the pulse width modulator. Although it is somewhat more complex in implementation, the advantage is accuracy and stability although if errors do occur, they could result in complete loss of control.

4. Isolating the digital power path. While also offering high accuracy, placing all the control - including the power switch drive - on the secondary side makes the isolation task more difficult due to the power levels and stringent waveform requirements. It also carries along the added burden of a separate isolated starting circuit, or possibly a complete auxiliary power supply, and either of these means a third crossing of the isolation boundary.

Before embarking on a more detailed discussion of the above alternatives, mention should be made of an additional choice, and certainly the simplest one from an isolation standpoint, which is to not have a feedback path at all.

Conversion Without an Overall Control Loop

Clearly, the problems of isolating a control feedback path are sidestepped neatly by eliminating the feedback. The approach which offers the highest level of performance using this technique is shown in Figure 2 where a combination of voltage feed-forward or current-mode control, and secondary regulators can give excellent results. This circuit controls the power stage from the primary side with direct communication. This has the added benefit of reliable fault protection since input voltage and current levels can readily be monitored and reacted to with minimum delay. The control circuit must be either powered directly from the line - which would require very low current - or started from the line and then supplied by a primary-referenced, low-voltage auxiliary winding from the power transformer.

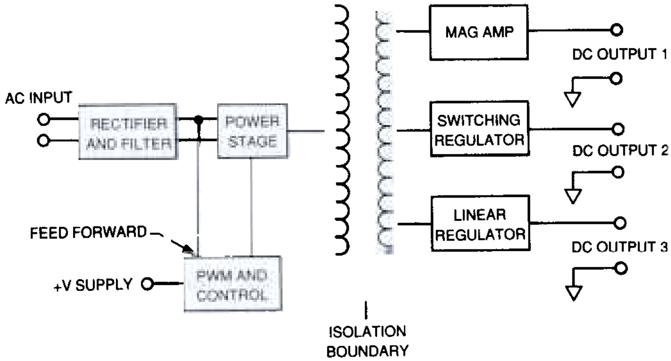

Fig. 2 -- Feedforward, No Overall Control Loop

Either a current-mode topology or a voltage feed-forward circuit which linearly adjusts the width of the PWM output pulse in response to changes in input voltage will provide a constant volt-second product to the primary of the power transformer. For circuit topologies other than discontinuous flyback, this will achieve a first-order line regulation. Higher accuracy, as well as regulation for load changes, is accomplished by the secondary regulators which, as shown in Figure 2, can be implemented in several ways. In general, a linear regulator is the simplest approach while a mag amp will be the most efficient.

As stated above, a high degree of performance can be achieved with this configuration. Its main drawback is the potential cost and reduced efficiency of the additional secondary regulators - a penalty which accelerates rapidly with increasing load current levels.

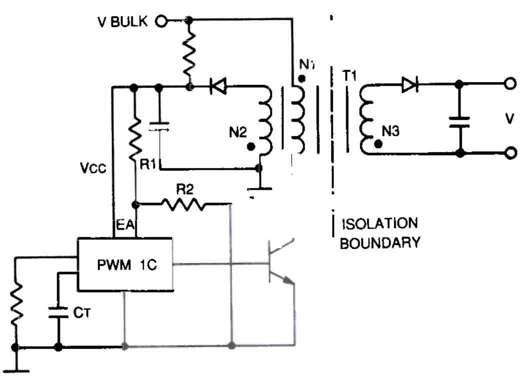

Fig. 3 -- Primary Control

Isolating the Control Loop

A simpler approach to a "no overall feedback" converter is shown in Figure 3. This circuit uses the same low-voltage, primary-referenced auxiliary winding which was mentioned above as a way of efficiently supplying power to the control circuit, but in this case, a non-isolated feedback loop is used to force the PWM controller to regulate its own supply voltage. The theory is that if the diode voltage drops are matched, and the transformer windings well coupled, the isolated output voltage will track this regulated primary-referenced auxiliary voltage. While this design may provide acceptable performance in low power applications, the problem is that both the above assumptions are weak - particularly the goal in achieving close coupling between windings which may need 3750 VAC isolation.

Isolating Feedback Control at the Output

An interesting and relatively simple method for isolating the measurement of the output voltage is shown in Figure 4. This circuit uses a secondary-driven amplitude modulator to transmit the DC output voltage value across an isolating pulse transformer to the primary side. Assuming the transformer is fully reset between each pulse, when Q_1 is turned on, C_C will charge to a value closely approximating the supply's output voltage, and then hold that value - with only a small decay through R_C - while Q_1 is off. While the easiest approach to driving Q_1 would be to use the supply's switching frequency from a secondary winding of the power transformer, there are at least two limitations: First, Q_1 will follow the duty cycle of the power transformer and it can be seen from the waveforms of Figure 4 that the average value of the peak-detected control voltage, V_C, will vary with duty cycle. Secondly, the bandwidth of this system will not be usable much above one-tenth of the switching frequen-

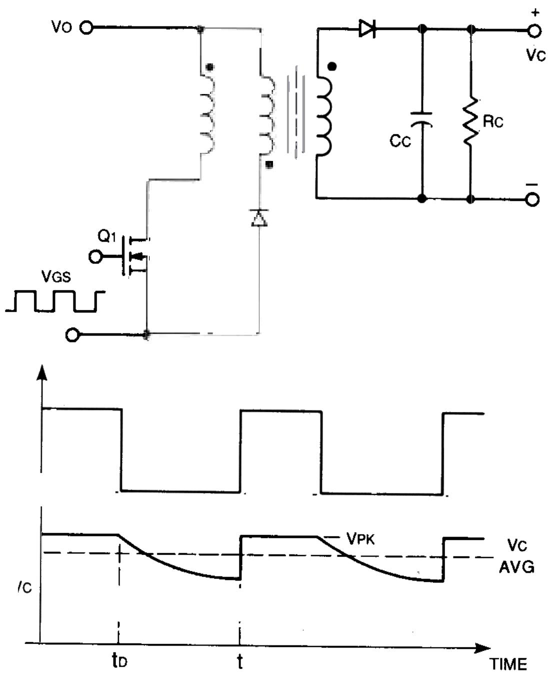

Fig. 4 -- Pulse Transformer / Peak Detector

cy which could unduly restrict a control loop. There is also a hard compromise in the value of R_C between measurement accuracy and negative slew rate.

The severity of these problems can be substantially reduced by using a separate oscillator to drive Q_1 with a much higher and constant duty-cycle frequency, but, of course, this is somewhat removed from the original premise of a simple circuit.

Isolating the Digital Power Path

This discussion will now jump from the output end of the control feedback path to the input side where a traditional isolation technique has been the use of a transformer, or transformers, between the PWM output drivers and the main power switches. This approach, as illustrated in Figure 5, puts all the control on the secondary side and with close DC coupling to the outputs, high accuracy and excellent protection for the load can readily be provided. The problem with this method is twofold: First, the transformers which couple the PWM commands to the power switches handle more than just information - they must also provide drive power to the switches, conditioned to insure reliable operation under all operating environments. The second complication is that secondary-side control will normally require an isolated power source, adding a third crossing of the isolation boundary and the added components of this auxiliary bias supply. It is for these reasons that this approach - while popular in the past - seems more recently to be relegated to very high power systems which can more readily absorb the added overhead cost, or applications requiring extensive "hand shaking" between the control circuit and output load-grounded logic.

Before leaving the subject of isolating the digital power path, there is another technique worthy of mention, although primarily for a historical perspective. This is the blocking oscillator circuit shown in Figure 6 configured as a free-running flyback converter. This topology uses base-current regeneration to turn the power switch on while turn off is effected by

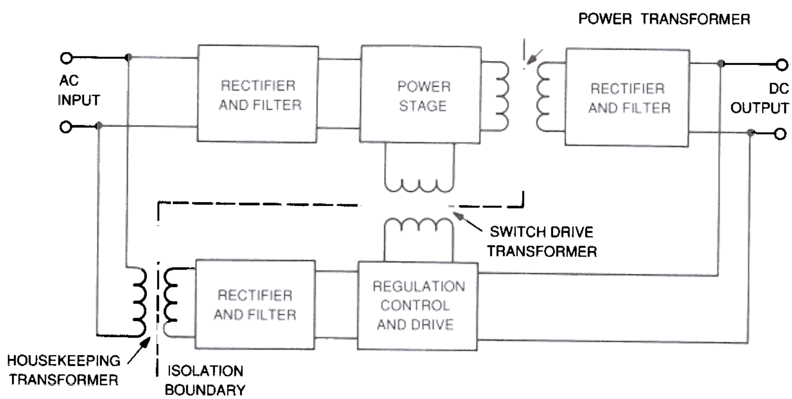

Fig. 5 -- Secondary Side Control with Isolated Switch Drive

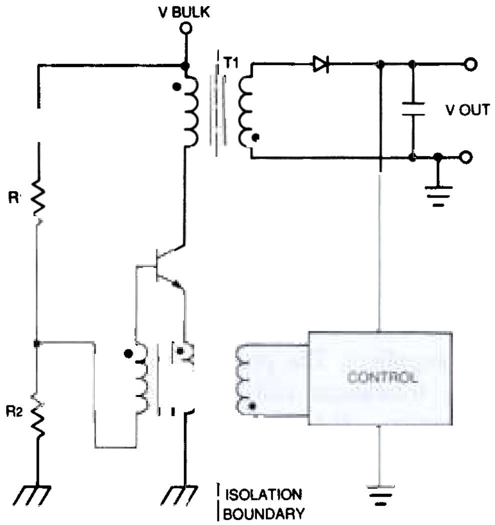

Fig. 6 -- Sec. Control, Pri. Blocking Oscillator

means of either a pulse transmitted across the isolation boundary by the secondary control circuit, or saturation of the base-drive transformer. While its extreme simplicity made this circuit attractive for low cost applications, its performance was hard to guarantee over a wide range of operation and, with the advent of inexpensive IC control chips, it is now primarily relegated to flyback supplies of less than 100 Watts.

Isolating the Analog Error Signal

This brings us to the most popular and widely used technique for isolation - placing the barrier between the analog and digital portions of the feedback path. This means between the error amplifier and the pulse width modulator, and obviously requires the control to be divided into two separate circuits - one on the primary and one on the secondary - with 3750 VAC isolation between them. Since this voltage is well beyond most IC technologies, a two-chip control solution is required, where all the approaches discussed earlier can, at least conceivably, be done with a single control IC. The allocation of circuit functions is usually as follows:

Secondary Side	Primary Side
Reference	Isolator Receiver
Error Amplifier	Pulse Width Modulator
Loop Compensation	Switch Drivers
Over-Voltage Protection	Starting Circuitry
Output Current Limit	Low-Voltage Sensing
Isolator Driver	Switch Current Limit

While there have probably been many isolating mediums proposed for communicating between these two sections, the only two which have demonstrated their practicality through widespread use are optical couplers and transformers. Although capacitors have also been suggested as a possible isolating medium, they must be high voltage types and with at least two required, this has thus far not been a very cost effective solution. Therefore, this discussion will be limited to optical and magnetic techniques. Since the information to be transmitted is a low-level analog control signal, the issues to be addressed, regardless of the medium, are accuracy, stability, bandwidth, and cost.

Optical Isolation

The basic optocoupler isolated power supply configuration is shown in Figure 7. An optocoupler is a remarkable device based upon the fact that semiconductor junctions can both emit and be affected by photon light energy. By passing a current through one junction, light is emitted, which then shines on another junction, causing that one to conduct a current. These two junctions need to be on separate chips - both to provide the isolation voltage capability and because, while silicon makes a good light detector, emitters are more efficiently made

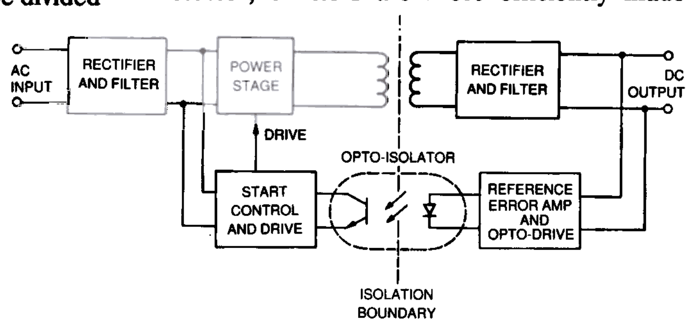

Fig. 7 -- Optocoupler Isolation of Analog Signal

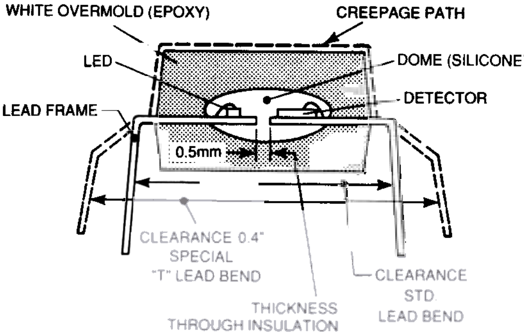

Fig. 8 -- Optocoupler Dome Package

from gallium arsenide. Early optocouplers were constructed with the two chips facing each other - a significant manufacturing challenge - but newer designs are now built with an internal reflective dome as shown in Figure 8. The external dimensions are those of the standard dual-in-line minidip plastic molded IC package, but usually with six, rather than eight leads. It should be noted that while there may be hundreds of optocoupler part numbers available, not all will meet the more stringent isolation specifications. For example, the standard DIL lead spacing of 0.3 inches means that the solder pads on the PC board will not meet the 8 mm creepage spec unless a slot is cut through the board between the input and output rows of pads. The alternative is to pick an optocoupler with the special 0.4 inch lead spacing indicated with the dashed lines in Figure 8.

On first glance, the optocoupler would appear to be an ideal isolating medium and, in fact, its popularity attests to its positive features. It is physically a very small device with a low selling price and it will transmit DC, as well as higher frequency information. There are, however, many characteristics which, if not troublesome, at least need careful consideration in the design process to insure a satisfactory application.

Optocoupler Design Considerations

The single most important parameter defining optocoupler performance is the device's "Current Transfer Ratio", or CTR. This is the ratio of output current to input current, and obviously determines the efficiency of the information transfer. Frustratingly, from a design standpoint, this parameter is not one of life's universal constants. Some of the variables which a designer must accommodate are outlined below:

1. Absolute value. There was a time when a CTR of 0.1 (10%) was a pretty good device but manufacturers have made major improvements to the technology over the years to the point where a CTR of 100% is readily available from most suppliers. The problem is that manufacturing tolerances still do not yield a tight distribution - the total spread of CTR values for a given device type might range from 40% to 200%. Recognizing that users can't live with that wide of a spread, most manufacturers use a sorting process to divide their manufacturing distribution into narrower ranges. For example, the CNY 17 optocoupler can be bought as follows:

Part Number	Min	Typ	Max
CNY 17-1	40%	60%	80%
CNY 17-2	63%	100%	125%
CNY 17-3	100%	150%	200%

Recognizing that these limits are somewhat arbitrary, it is certainly possible, depending on business considerations, to negotiate a tighter spec for a higher price. Another fact to consider is that if everyone were to select the same range, manufacturers would have to adjust selling prices in order to create a market for the rest of their distribution.

2. Driving current. There are actually two factors to consider here. First, the value of CTR is a strong function of input current through the light emitter. A typical relationship is shown in Figure 9 where it can be seen that while CTR = 100% for grade range 2 at an emitter current of 10 mA, it drops to less than 50% at 1 mA. The second factor is that CTR is referenced to input *current*, when it is usually an error *voltage* that is to be transmitted. Unless a voltage-to-current circuit is added, it must be remembered that the light emitter is

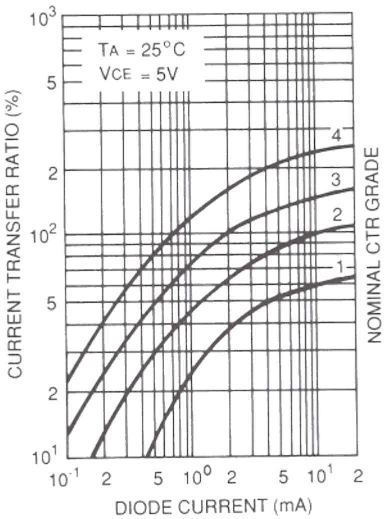

Fig. 9 -- CTR Variation vs. LED Current

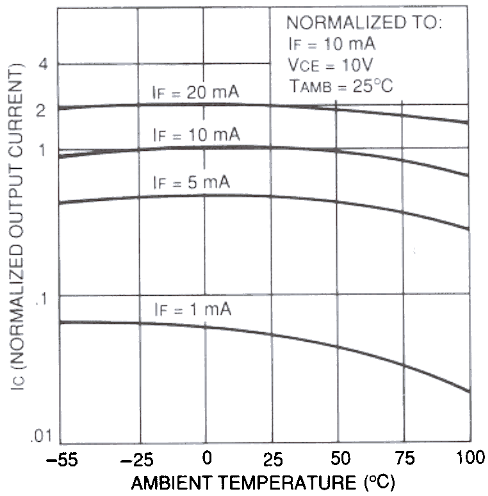

Fig. 11 -- Detector Current Vs. Temperature

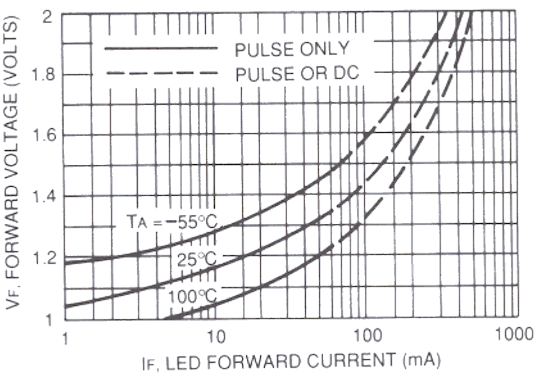

Fig. 10 -- LED Forward Current vs. Voltage

actually a forward-biased diode with a non-linear relationship between voltage and current as shown in Figure 10. Both of the above non-linearities can be troublesome, first in determining the actual CTR of a given device and, secondly, for introducing a non-linearity into the feedback gain.

3. Temperature. The temperature characteristics of a typical optocoupler are shown in Figure 11 which indicates a drop in CTR value of about 20% at both hot and cold temperature limits. To this must be added the input diode's T.C. of Figure 10 if the optocoupler is to be driven from a voltage source. One other consideration is that the maximum ambient temperature specified for the vast majority of available devices is only 100°C, precluding their use in military or high temperature environments. This limit is primarily a packaging and business issue, rather than a limitation caused by the semiconductors, and there are a few suppliers who have offered optocouplers in a high temperature, hermetically sealed package; however, they are quite expensive.

4. Stability. One of the more significant problems of early optocouplers was a degradation in CTR which occurred with respect to time. This was not a predictable wear-out mechanism - like a lamp filament, for example - but caused by random crystal defects in the structure of the light emitters. Here also, manufacturers have made great improvements and now most can claim a shift of less than 1%/1000hr, although few will offer any guarantees. A typical manufacturer's data is given in Figure 12 from which it could be concluded that one can be 60% confident that no more than 5% of the population will change by more than 10% in 20,000 hours. Recognizing that this degradation is accelerated with higher currents through the emitter diode, the fact that this data was taken at 60mA should provide further comfort to the user.

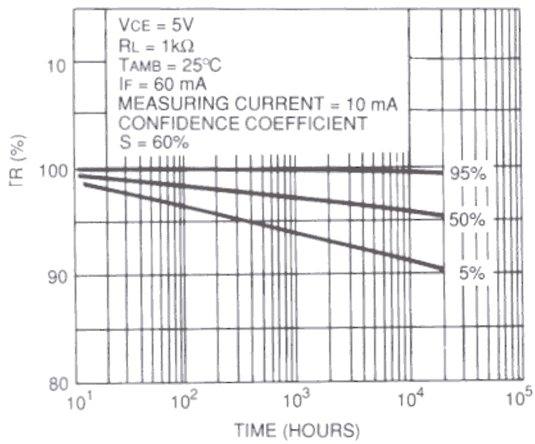

Fig. 12 -- CTR vs. Operating Life

5. Bandwidth. To be an effective optical detector, the output transistor must have a large area to collect the photon energy. This gives it a large collector-to-base capacitance which can introduce a pole into the feedback loop in the range of 1kHz to 40kHz. A Bode plot of the amplitude and phase response of a typical optocoupler is shown in Figure 13 but these curves can vary considerably from unit to unit.

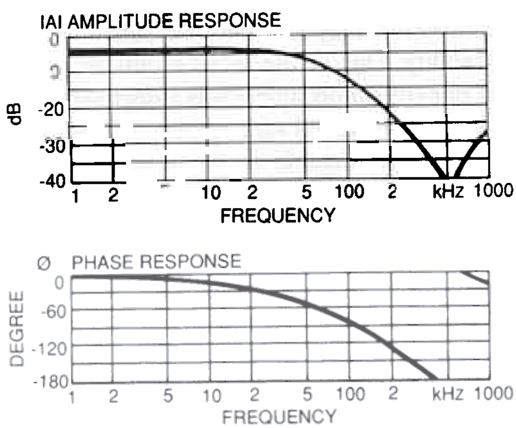

Fig. 13 -- Typical Optocoupler Freq. Response

There also may be significant variability if the operating bias is not well defined. Certainly, as the loop bandwidth reaches into the kilohertz region, this pole must be accounted for and considered in the overall system response analysis. Bandwidth increases with increasing current, but then so does the degradation described above. Another way to increase bandwidth is to use a cascode detector circuit as shown in Figure 14.

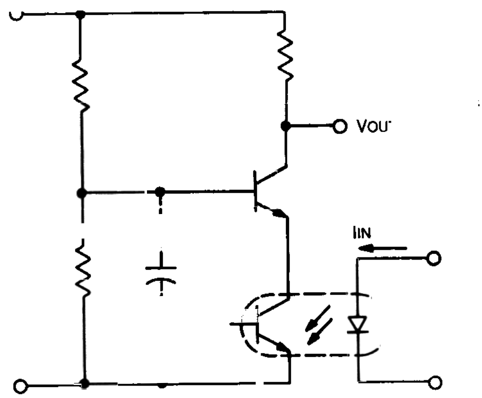

Fig. 14 -- Increased Optocoupler Bandwidth with Cascode Detector

Regardless of the above concerns, optocouplers have been successfully applied in a broad range of circuits and it should be useful to examine some of these configurations.

Applying Optocouplers

While undoubtedly a large variety of discrete component circuit configurations have been used with optocouplers, most of these are no longer cost effective in comparison to integrated circuit solutions, which will be the emphasis in this discussion.

Before addressing driver circuits for the light emitter, it's worth mentioning that interfacing the optocoupler's detector with the primary-side PWM circuitry can be done with either common-emitter or common-collector configurations as shown in Figure 15. The C-E circuit is usually applicable to PWM chips with transconductance error amplifiers, such as the UC3524. With a pull-up resistor to set the detector current, this circuit could go right to the Compensation pin and override the error amplifier. Problems with this approach are that the collector-base capacitance may severely limit the bandwidth, and that too much bias current could yield a saturation voltage too high to allow the PWM to go to zero.

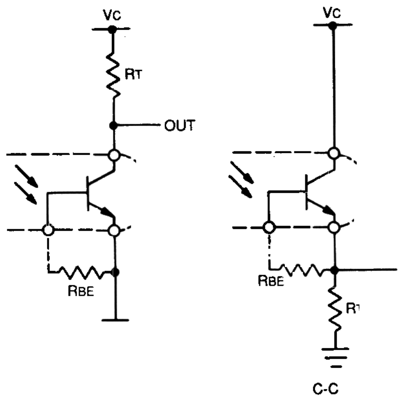

Fig. 15 -- Alternative Detector Connections

The C-C circuit is more popular but its output usually needs to be inverted on the primary side to allow the power supply to start. This is because no secondary output voltage means no driving energy to the input of the optocoupler and therefor no conduction at the output, or a command of zero PWM if connected directly to the modulator. However, the error amplifier in all common PWM controllers can easily be configured as a low, or unity gain invertor and is readily driven by the low output impedance of the emitter of the optocoupler's detector.

One additional comment with respect to the detector transistor: It is not necessary to connect the base to anything but this is a high impedance point which can be quite noise sensitive. It is important to remember this when locating the optocoupler within the power supply. For both noise considerations, as well to insure the complete turn-off of leaky detectors, it is often advisable to add resistance from base to emitter - 300 to 500 kOhms, perhaps. Alternatively, optocouplers can be acquired which have no base lead, minimizing the noise pickup.

An obvious choice to drive the light emitter of an optocoupler is one of the many IC linear regulator control chips. One of the early choices was the uA723, used as shown in Figure 16. This very inexpensive circuit includes the error amplifier and the reference, as well as a relatively high current driver with enough headroom to allow R_D to set the emitter current. Some problems with this circuit are the fact that the uA723 requires at least 9.5 Volts, the output can only go about 2V lower than the inverting input, and the error amplifier is poorly characterized for gain compensation. One trick that has been used with this circuit to accommodate the wide range of possible CTR values is to shunt R_D with a lower resistance in series with a low-voltage, soft knee Zener diode. This makes R_D appear non-linear providing more current to drive low-CTR optocouplers.

A second choice for an optocoupler driver is the UC3838 as shown in Figure 17. While this device was designed as a controller for mag amp switching regulators, it has all the necessary elements for an optocoupler application along with the added benefits of 5 Volt supply operation, a current source output, and a well

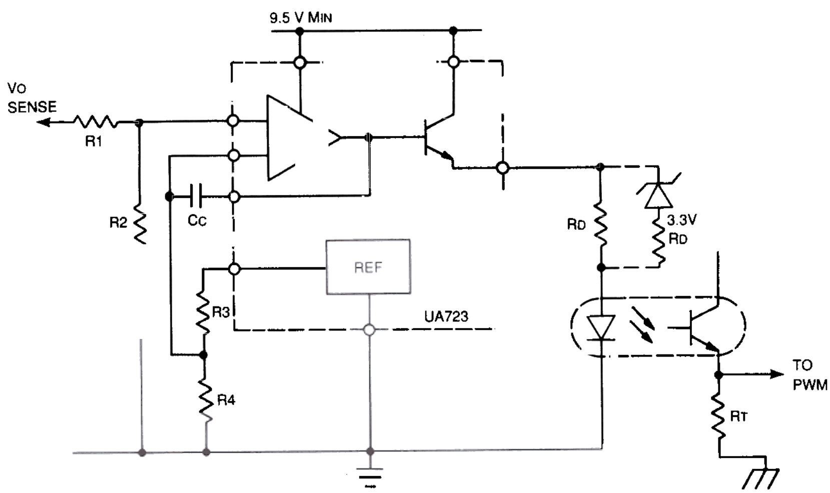

Fig. 16 -- Using a µA723 to Drive an Optocoupler

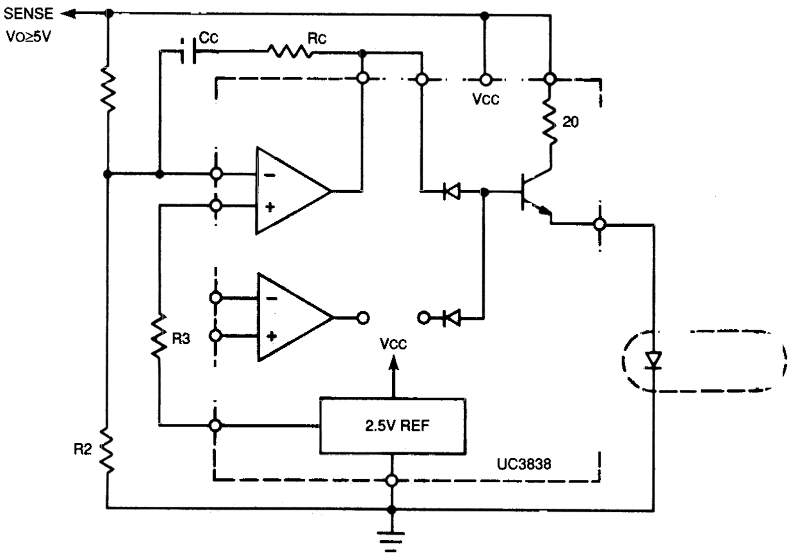

Fig. 17 -- Using the UC3838 as an Opto Driver

available so compensation can only be effected by feedback from the output transistor's collector to the non-inverting input. Since the transistor's gain is a function of its current, compensation is difficult to predict and, in fact, there are some values of capacitive load for which this device is unconditionally unstable.

Another difficulty is that since the internal reference is common to the anode, the optocoupler can only be driven from the cathode. While this is certainly possible, it can create another compensation problem in applications as shown in Figure 19 where the optocoupler is supplied from the same voltage source it is monitoring. While the action of capacitor C with the input divider impedance can establish a frequency break point, one might assume that above this frequency, the gain will roll off to a negligible value at high frequencies, but such is not the case. The reason is shown in Figure 19 where the circuit is redrawn to illustrate the negative feedback present in this configuration. Since R_D is used to convert the amplifier's output voltage into a current through the emitter diode, we can write

defined error amplifier. In addition, there is a second op amp available to provide some auxiliary function such as load current sensing or over-voltage protection.

That brings us to a third choice, the TL431, another device often selected on the basis of cost. This part was also designed for another function - an adjustable shunt regulator - but it includes the required reference, amplifier and driver; all contained in a three pin package. The equivalent circuit for the TL431 is shown in Figure 18. Note that the terminal designations can be somewhat confusing as the pin called "reference" is normally what would be considered the sense, or programming input.

While the TL431's three pin configuration keeps interfacing simple, it also limits versatility and creates some application problems. Neither the op amp's output nor inverting input are

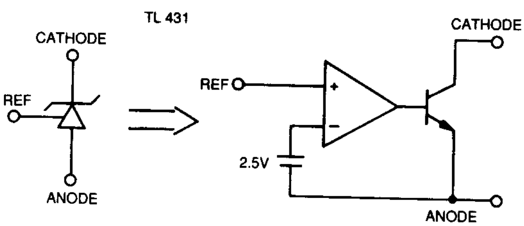

Fig. 18 -- TL431 Adjustable Shunt Regulator

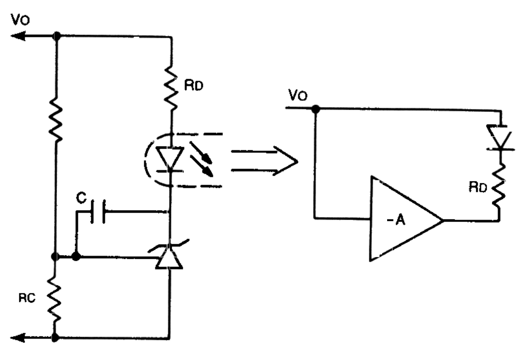

Fig. 19 -- Negative Feedback Limits Min. Gain

$$\Delta I_D = \frac{\textit{Change in voltage across } R_D}{R_D}$$

But since the change in voltage across R_D is ΔV_O - (-A)ΔV_O,

$$I_D = \frac{(1+A)\Delta V_O}{R_D},$$

and the transconductance gain is

$$Gain = \frac{\Delta I_D}{\Delta V_O} = \frac{1+A}{R_D}$$

As A rolls off to zero at high frequency, the gain goes to $1/R_D$, a finite positive value.

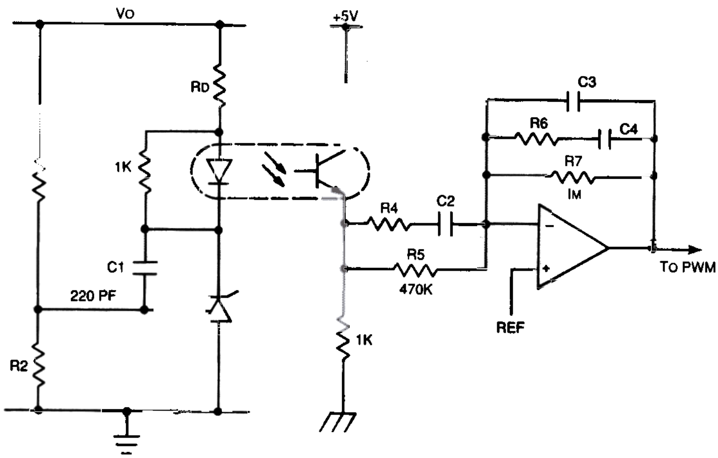

Fig. 20 - Preferred Compensation Location with TL431

One way around this problem is to use a separate, or regulated supply to bias the optocoupler - a simple solution if such a supply happens to be available. An alternative approach is to not rely on the driving stage for loop compensation but place it around the error amplifier on the primary side as shown in Figure 20. A small capacitor is still used with the TL431 to keep ripple and noise from overdriving that device, while the poles and zeros to provide system stability work on the other side of the isolation. Note that the error amplifier starts with a DC gain of two to get a full 4V output swing with only 2V from the opto-transistor.

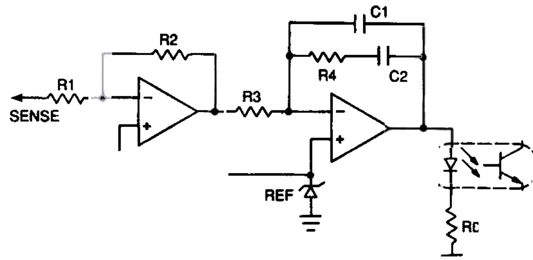

Fig. 21 -- Two Op-Amps for Proper Phasing

Of course, it is always possible to replace the TL431 with a separate op amp, in which case the optocoupler can be ground referenced, eliminating the above negative feedback problem; however, it's not quite that simple. Starting and phasing considerations require that an increasing sense voltage increase the current through the optocoupler. This means that a single op amp driver must be used in a non-inverting configuration, complicating compensation since the reference diode will be on the inverting input. Fortunately, inexpensive dual op amps, such as the LM358, allow an extra inverting op amp to be added as in Figure 21 at minimal cost.

With two op amps, it's a relatively simple next step to add transistor Q_1 as shown in Figure 22. This provides a current-source drive to the optocoupler which eliminates both the effects of supply-voltage variation and the opto-diode's logarithmic V-I

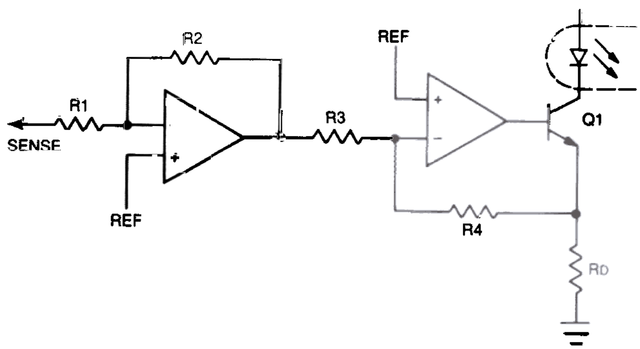

Fig. 22 -- Current Source Optocoupler Drive

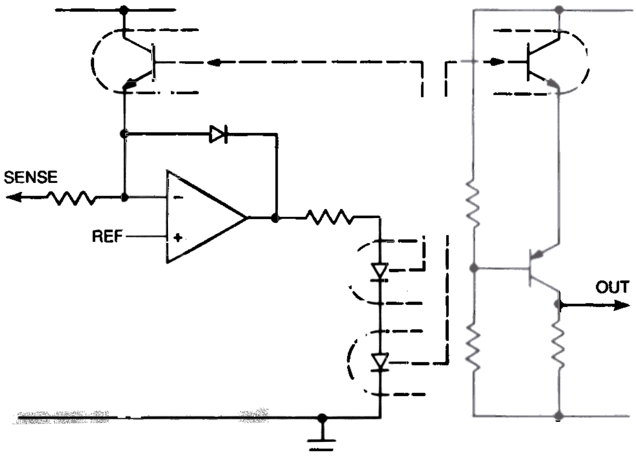

Fig. 23 -- Two Matched Optocouplers Cancel CTR Changes

characteristic, and is thus probably the most ideal driving circuit.

One final application, where possible variation in optocoupler CTR values would be unacceptable, is shown in Figure 23. This approach uses two optocoupler devices which are matched as closely as possible. One then provides the negative feedback to compensate for changes which occur to them both, making the loop gain constant. Dual opto devices in a single package are available to make this implementation easier; however, as the technology has improved, it is questionable whether this is very cost effective.

Transformer Isolation

The use of a transformer to provide isolation for the control signal would seem a natural approach as there will already be a transformer isolating the power path. The problem, of course, is that the control signal must include DC information to hold the power supply's output constant, and to get DC through a transformer requires some form of carrier modulation. The required circuitry would normally be complex enough to preclude this approach for most applications, but an integrated circuit has been developed to minimize the complexity and provide a viable, low-cost solution. This device, the UC3901, is shown in a typical application in Figure 24. In addition to the required reference and error amplifier, the UC3901 includes a high-frequency oscillator whose amplitude is modulated by the output of the error amplifier. The use of

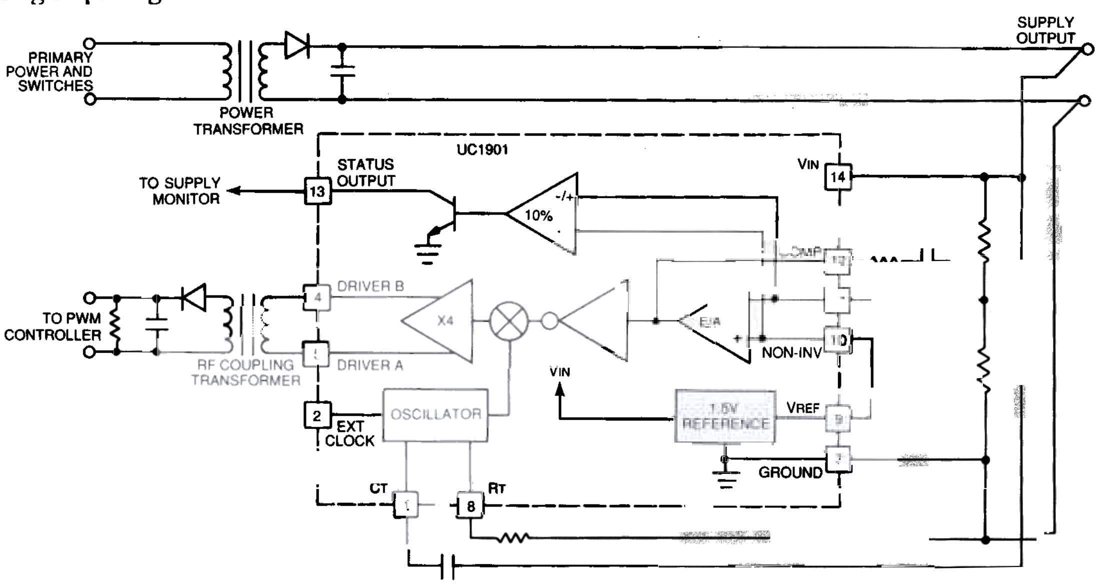

Fig. 24 -- The UC1901 Provides Isolated Feedback Using a Small Signal Transformer

amplitude modulation allows simple diode detection on the primary side to recover the control information and interface it to any of the common choices for primary-side PWM controllers.

There are several significant benefits with this approach. First, the use of a high-frequency carrier - up to 5 mHz - keeps the coupling transformer both small and inexpensive, as well as allowing a high bandwidth for the control information. Secondly, the transformer provides a transfer function fixed by the turns ratio, eliminating all of the variables associated with optocouplers. Finally, the transformer, as well as the UC3901 (UC1901) can be obtained capable of meeting the full military temperature range.

Isolating the Digital Signal Path

The fourth, and last, point in the feedback control path where we might consider placing the isolation is within the digital signal processing section of the pulse-width modulator. This infers that all the analog processing is done on the secondary side so that accuracy and stability issues are defined prior to reaching the isolation medium. Only digital information crosses the isolation boundary, a task which can be accomplished relatively easily with either optics or magnetics. That's not to say that this isolation approach is trivial as there remains several important issues, most notably circuit complexity and freedom from susceptibility to noise transients; however, some interesting work has been done, and is continuing in this area.

The most common generalized approach is to have two PWM modulators, one on each side of the isolation. The one on the primary is dominant during start-up or fault conditions, but once the output voltage begins to rise, the secondary PWM takes command and transmits switching information back to the primary controller through a pulse transformer. An early integrated circuit implementation of this approach is the two chip set shown in Figure 25. The IP1P00 primary circuit contained a free running but synchronizable oscillator, PWM with duty cycle limit, power switch current limit, soft-start and under-voltage lockout, as well as a pulse transformer interface. The IP1P01 secondary circuit included the reference, error amplifier, current sensing, pulse width modulator, and transformer interface. Because only pulse information is transmitted across the isolation, the transformer can be as simple as a single turn each for the primary and secondary windings on a small toroidal core.

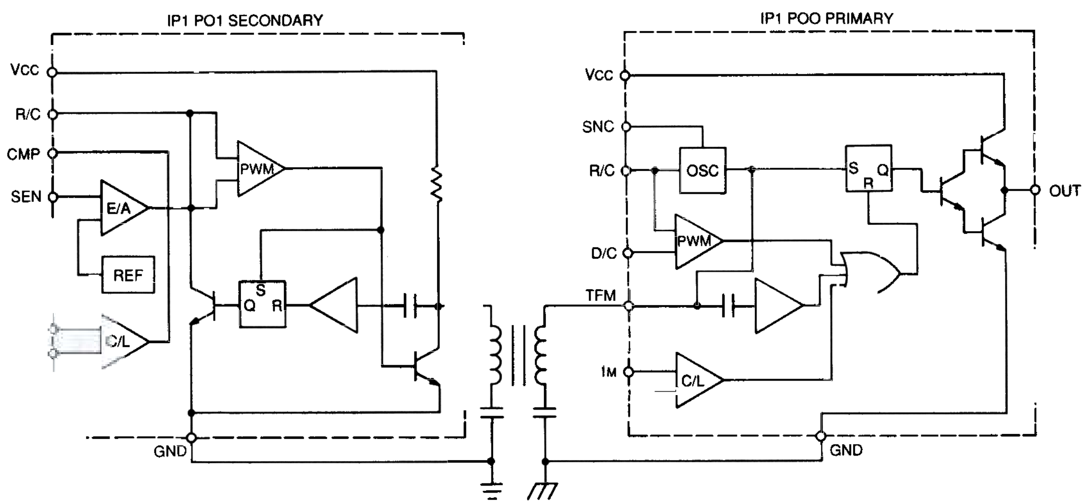

Fig. 25 -- Two-Chip Set Communicates Secondary to Primary by means of Pulse Transformer

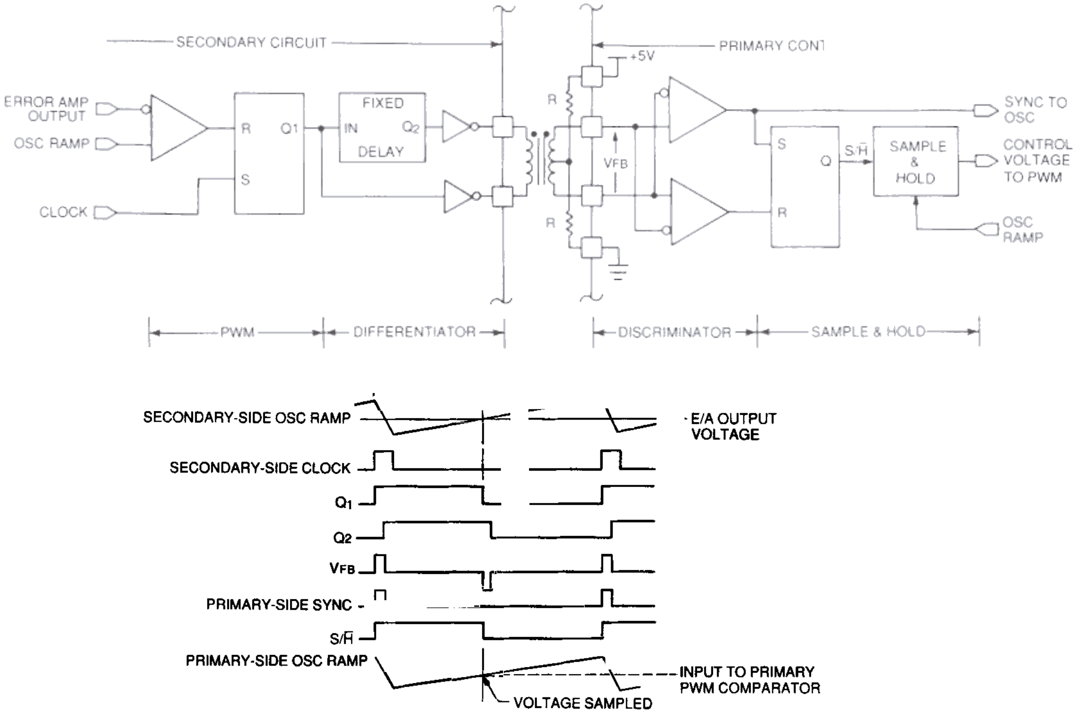

Fig. 26 -- New Two-Chip Set Transmits DC Feedback and Clock Sync Through Signal Transformer

A more sophisticated approach is currently under development at Unitrode to allow the isolation transformer to perform more functions than merely regulating the output voltage. This will also be a two chip set with a pulse width modulator block on each chip. The communication across the isolation boundary will be with amplitude and polarity sensitive pulses to transmit frequency synchronization and regulation control from secondary to primary simultaneously with under-voltage and fault shutdown indications from primary to secondary.

Figure 26 illustrates the secondary-to primary control communication scheme. Note that only that portion of each circuit directly associated with this communication link is shown in the figure. The function of the secondary circuit is to generate a fixed-width positive pulse at the start of each clock cycle, and a fixed-width negative pulse when the PWM comparator senses the crossover between the oscillator ramp waveform and the error amplifier output voltage.

The discriminator on the primary side then separates out the positive transmitted pulse and uses it to synchronize the primary-side oscillator. It also uses the time difference between positive and negative pulses to define a sample point at which time the instantaneous value of the primary oscillator ramp waveform is held as the control voltage which becomes the input to a conventional current-mode pwm stage. With this technique, not only will the overall regulation be provided by a feedback signal derived from the actual load voltage, but the switching frequency may also be set by locking onto a standard referenced to the load side of the isolation.

While pulse timing defines the above information, primary-side logic levels can be simultaneously transmitted to the secondary side by modulating the amplitude of these timing pulses. The mechanism for accomplishing this is shown in Figure 27, which shows this portion of the circuitry on each of the IC's.

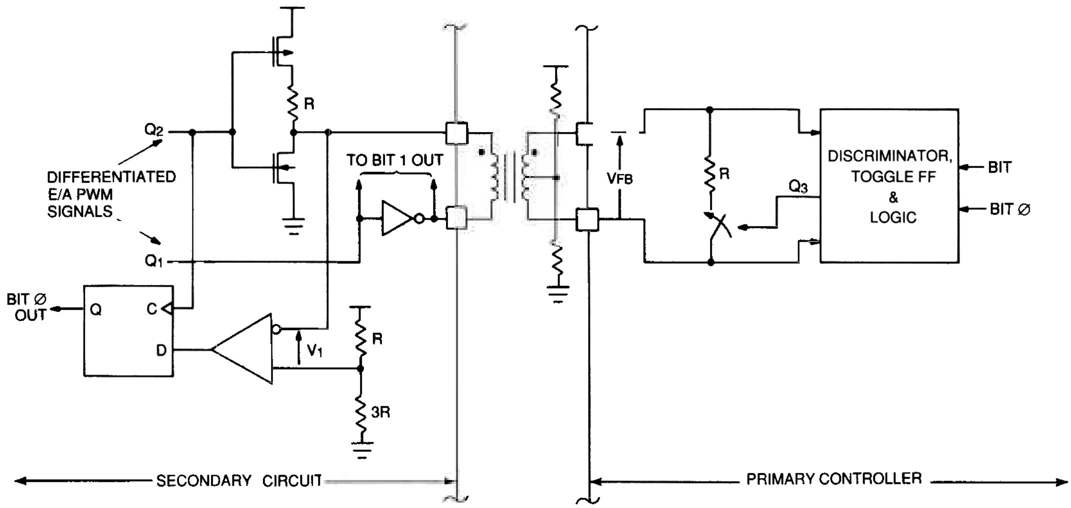

Fig. 27 -- Same as Fig. 26 with Additional Two Logic Level Signals Transmitted from Pri. To Sec.

With a known source impedance in the pulse generation circuit on the secondary, changing the load impedance on the primary will affect the pulse amplitude back on the secondary where it can be sensed and used to provide digital flag information. Because of the tolerances associated with this system, the resolution will only permit the presence or absence of a digital level to be detected, but this can be done separately for the positive and negative transmitted pulses allowing two bits of information to be received on the secondary side. For example, low input supply voltage and a primary fault shutdown.

With this system, a single signal-level transformer is used to simultaneously couple four independent signals, two in each direction, across a high-voltage isolation boundary - a substantial and valuable extension of the technology available to implement off-line isolated power supplies.

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